Comparison between The Energy-Based Hysteresis Model and The Jiles-Atherton Model in Finite Element Simulations

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Abstract

This paper focuses on ferromagnetic hysteresis phenomena, a crucial point in the evaluation of iron losses in the modelling of electromagnetic devices. The Energy-Based hysteresis model appears as a convenient candidate for the representation of magnetic hysteresis within numerical simulations. Built from thermodynamic principles and inspired by dry-friction like mechanisms in viscoplasticity, this naturally vectorial model offers the possibility to calculate directly the stored and dissipated energy at any time, not only after the closure of minor hysteresis loops. The model parameters are identified from common material measurements and their number is not limited, allowing for a trade-off between accuracy and complexity. In this paper, this model is incorporated into 2D magnetic vector potential finite element formulation simulations and compared with the very popular Jiles-Atherton hysteresis model on the basis of their ability to accurately and efficiently predict measurements from an experimental set-up constituted by a three limbed ferromagnetic core.

1 Introduction

The nonlinear hysteretic behavior in ferromagnetic materials remains one of the main difficulties to take into consideration in electromagnetic modelling. Currently, the most widely used hysteresis models are the Preisach model [1] and the Jiles-Atherton (JA) model [2]. The former can give the most accurate description of hysteretic material law but has no interpretation in terms of energy and requires a vast amount of experimental data. The latter is much simpler to implement but can sometimes lead to nonphysical results. Moreover, both are natively scalar models and their numerous vector extensions have no real physical justification. On the other hand, the naturally vectorial Energy-Based (EB) hysteresis model from [3, 4] is built on consistent energy arguments. Stored and dissipated energies are thus known at any moment in time. Moreover, unlike the JA model, the number of parameters, identified from common material measurements, can be adequatly chosen to reach a given level of accuracy. First, this paper clarifies the parameters identification strategy introduced in [4] for the EB hysteresis model. Then, within a 2D finite element magnetic vector potential formulation context, the EB and JA models are included in the simulation of a real transformer device and compared with available experimental measurements.

2 Parameters Identification of the Energy-Based Hysteresis Model

The EB model assumes the dry-friction-like pinning of the domain walls. In practice, the distribution of the pinning strength values is discretized in N cells. Therefore, the EB model is fully characterized by the anhysteretic magnetization curve, usually fitted by a double langevin function, and the N couples of parameters (ω^k,κ^k) which represent the weight and the pinning strength associated to each cell. This paper proposes to control the model accuracy thanks to an automatic parameters identification strategy based on common experimental measurement data: the virgin magnetization curve and the $h_c(h_p)$ material curve, where h_c is the coercitive field of a minor symmetric closed loop, for which the peak magnetic field is h_p.

3 Finite Element Simulations

Preliminary results are shown in Fig. 1 and Fig. 2. The computed currents with the JA model and a 3-cell EB model exhibit already an excellent agreement with the measured currents. A larger difference appears between simulated and measured flux densities at the point 1. In the full paper, magnetic anisotropy will be taken into account to reduce this difference and the identification strategy of the EB model parameters will be improved. Nevertheless, the 3-cell EB model and the measured curves present roughly the same shape.

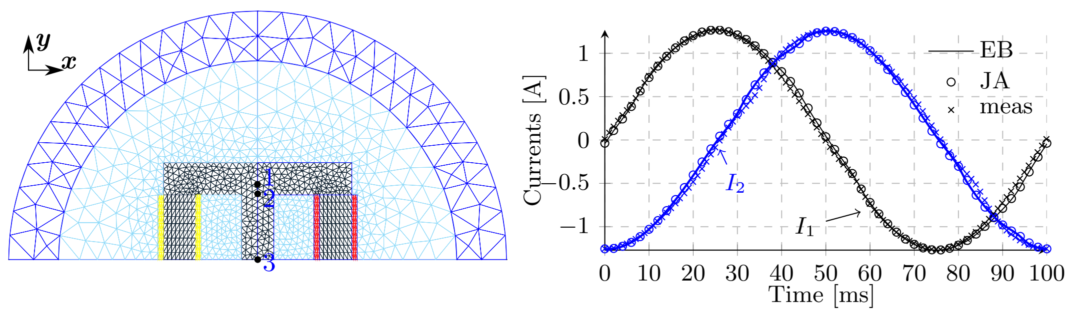

Figure 1: [Left] Finite element mesh of the TEAM Workshop Problem 32 with location of 3 points; [Right] Measured and simulated currents in the primary (I_1) and secondary (I_2) windings.

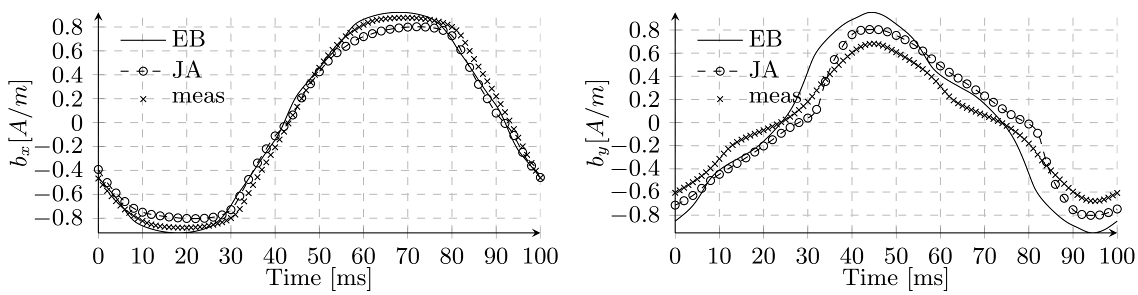

Figure 2: Evolution of the $x-$ [Left] and $y-$components [Right] of the magnetic flux density $\boldsymbol{b}$ at point 1.

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